Water Desalination Plants Performance Using Fuzzy Multi-Criteria Decision Making

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Abstract: - Countries which do not have adequate supply of freshwater sources like Kuwait resort to using desalination plants to meet their demand. Kuwait had used Multi-flash desalination (MSF) plants sine the 50's of the last century to satisfy its ever increasing demand. Many new and more efficient and cost effective desalination technologies are currently available. Kuwait is in the process of building new desalination plants, and has to seize this opportunity to consider using other desalination technologies instead of MSF plants. In this work, an attempt to make to bring to the attention to the decision maker the performance and suitability of the different technologies using a fuzzy multi-criteria decision making technique. The preference is based on six criteria (factors) for comparing three commercially available desalination technologies, i.e., Multi-stage flash (MSF), Multi-effect desalination (MED), and Reverse osmosis (RO). The study found that the amount of energy used in these plants should be most important selection criteria followed by the amount of pre-treatment required. The most preferred technology is RO according to this study.

Key-Words: - Freshwater, Decision maker, Preference, Reverse osmosis, Multi-stage flash, Multi-effect desalination

1 Introduction

Freshwater is essential for life and living species. Many countries have abundant freshwater supplies, while others have limited resources. The problem of the scarcity of freshwater supplies is apparent in the Gulf Cooperation Council (GCC) countries where freshwater resources are below poverty levels. In these countries, the freshwater demand has increased from 4.25 billion cubic meters (bm³) in 1980 reaching 29.3 bm³ in 2000 [1]. Freshwater in these countries is used for domestic, industrial, and agricultural purposes. Therefore, desalination technologies have been used extensively in these countries to produce freshwater to cover the progressive increase in demand. The GCC region accounts for around 45 percent of total desalination capacity in the world $\overline{[2]}$. Energy is essential for desalination plants. It accounts for some 20 to 30 percent of total water production costs, depending on the plant design. Energy does not present an obstacle, since the GCC countries are oil rich countries. Petroleum reserves in these countries was estimated at 468.2 billion barrels in 1999, representing 45 per cent of the world's total proven reserves for that year, whereas the natural gas reserve totalled 22,675 bm³, representing 82 per cent of the total natural gas in Western Asia region [22].

Kuwait is one of the GCC countries has a small, relatively open economy dominated by an oil industry and government sector. The proved crude oil reserves of the country is about 10 of the world reserves accounting for nearly half of the GDP, and 95% of export revenues. Over the last three decades, Kuwait has witnessed an unprecedented economic and social transformation, since a large portion of the oil revenues has been used to modernize the infrastructure and improve the living standards of the population. Water supply and sanitation services have been made accessible to a large percentage of the population where life expectancy has increased by 10 years, and illiteracy rate has declined significantly. In addition, all services are provided at highly subsidized prices, in economics where direct and indirect taxes play a marginal role as sources of government revenues. Kuwait suffers from an acute shortage of potable water resources, where the average annual rainfall ranges from 70 to 130 mm. This scarcity problem if not solved, could eventually lead to a severe shortage in water supply. Compared to international standards, where the required sustainable amount of water per person is restricted

to be around 1000 cubic meters (m^3) , Kuwaiti national would get far less.

The demand for freshwater in Kuwait has increased substantially over the years. The mean per capita consumption has risen from 4581 Imperial Gallons (IG) in the year 1960 to 9252 IG in 1970 then to 16734 in 1980. In year 2000, the mean per capita has reached 39,631 IG from 29583 IG in 1992, and it has finally reached 35229 IG in 2007. This per capita is considered as one of the highest in the world. The installed desalination has also increased dramatically (Table 1); it had reached 286.8 million imperial gallons (MIG) in 1995, 315.6 MIG in 2000, and 317.1 MIG in 2005. In fact, while the installed capacity of desalination plants was 447.5 MIG in 2007, the gross maximum consumption reached 380.2 MIGD.

Table 1, Installed Capacity of Desalination Plants inKuwait During 1980-2009

Year	Installed Capacity (MIG)	Mm ³
1980	100	0.45
1985	215	0.98
1990	252	1.15
1995	286.8	1.15
2000	315.6	1.30
2001	315.6	1.43
2002	315.6	1.43
2003	315.6	1.43
2004	315.6	1.43
2005	317.1	1.44
2006	355.6	1.62
2007	447.5	2.03
2008	462.5	2.10
2009	462.5	2.10

Source: Ministry of Energy, Statistical Yearbook, Water 2005, Kuwait [20].

Moreover, the total installed capacity is projected to 673 Mm³ in the year 2010 and is projected to reach around 1488 Mm³ in 2025 (Table 2). The energy required to operate theses plants is very high, it has reached 515,414 billion BTU in 2007 with a cost of around 4 billion USA dollars, Ministry of Electricity and Water Statistical Year Book, 2008 [20].

Commercially available desalination techniques are categorized into two types, i.e., distillation and membrane–based technologies. The distillation processes transform water into vapour then condense it into a liquid state. This process requires power in the form of thermal and electrical energy. Commercially available desalination techniques include multistage flash (MSF), multi-effect desalination (MED), and vapour compression (VC). Membrane–based desalination techniques consume power in the form of mechanical or electrical energy. Two processes under this category are commonly used, i.e., reverse osmosis (RO), and electro-dialysis (ED). However, the latter is mainly for brackish water desalination [3]. Although several desalination technologies are used in the GCC, MSF is dominant and it accounts for approximately 80 per cent of the world's plants.

Table 2, Total and Per Capita Freshwater Demand Projection for Kuwait in million cubic meter (mm³) until 2025

201067360820158777002020114280620251488928	Year	Total (Mm ³)	Per Capita (l/c/d
20158777002020114280620251488928	2010	673	608
2020114280620251488928	2015	877	700
2025 1488 928	2020	1142	806
	2025	1488	928

Source: Ministry of Energy, Statistical Yearbook, Water 2005, Kuwait [20].

1.1. Groundwater

The principal groundwater resource in Kuwait is contained with Dammam aquifer, a non-renewable resource, which is recharged through underflow from Saudi Arabia and Iraq. However, this resource is relatively saline and not suitable for potable use, but can be used for agriculture purposes. As for fresh underground water, limited quantities were discovered at both Rawadatain and Um-Al-Aish fields. Pumping operations commenced in 1962, the estimated natural reserve of both fields is about 40,000 imperial gallons.

1.2. Wastewater Treatments

In order to meet the rapid expansion of urban areas and increasing population growth, Kuwait has build wastewater treatment plants, rigorously and safely to treat sewage after collection for reuse. Huge investments are made in order to expand the coverage of sewage treatment systems. On the basis of the amount of treated seawater compared to the total produced drinking water, the coverage rate of sewage collection and treatment system is in the range of 20-40%, lagging far behind water supply services by 80-90%. Hence Kuwait covers 60% of its water supply through this system. Kuwait plans to increase its supply from 260 MCM to 340 MCM by 2020.

2 Available Technologies

Several desalination plants technologies are available commercially for seawater desalination. In this study three of the most extensively used ones are assessed. A general description of these three desalination technologies is presented below:

A. Multistage flash desalination (MSF): In this process, the seawater feed (brine) is and heated to a high pressurized temperature ranging from 90 to 125 Celsius. The heated liquid is discharged into a chamber which is held below the saturation vapour pressure of the water, a fraction of its water content flashes into steam. The suspended brine droplets are removed from the flashed steam as it passes through a mist eliminator and condenses on the exterior surface of transfer tubing. The condensed liquid drips into trays as hot distilled water. The circulating stream, flowing inside the tubes that condense the vapour in each stage, serves to remove the latent heat of the condensation. Hence, the circulated brine is preheated to nearly the maximum operating temperature of the process, while recovering the energy of the condensed vapour. The preheated brine is finally brought up to maximum operating temperature in the prime heater supplied with steam from an external source boiler (Fig. 1).



Fig. 1, Detailed representation of the multi-flash desalination plant.

B. Multi-effect distillation (MED): In MED the incoming feed water is heated and then passed through a series of evaporators. In the first, effect vapour is released from the hot brine, which lowers the brine temperature. Afterwards, the brine is transferred to the second evaporator, where it comes in contact with one side of a series of tubes. The water vapour produced in the first evaporator is also transferred to the second evaporator where it condenses on the

outside of the tubes. The heat which is produced during the condensation process is transferred back to the brine, thereby boiling and further evaporating the brine in the second evaporator. The vapour pressure in each succeeding evaporator is lowered to permit boiling and further evaporation at successively lower temperatures in each evaporator (Fig. 2).



Fig. 2, Arrangement for multi-effect desalination process with backward feed.

C. Reverse Osmosis (RO): In this process, feedwater is first pretreated to remove suspended solids. Pretreatment can vary from cartridge filter type, multimedia filter, and to micro/ ultra filtration in some cases. The feed is chemically pretreated and pH adjusted, depending on the type of membrane used. The pretreated feed is then pressurized to the needed value depending on its salt content and passed through the RO membrane. Brine is the byproduct of the process, and it has a higher salt concentration than the brine produced by the thermal processes. The process can achieve up to 40% recovery from sweater and 75% from brackish water application (Fig. 3).



Fig. 3, A schematic presentation of the reverse osmosis plant.

3 The Fuzzy Analytic Hierarchy Process (FAHP)

The analytic hierarchy process (AHP) was developed by Thomas Saaty in 1970's [24]. It is widely used for multi-criteria decision making and has been successfully applied to many practical decision making problems. Mustafa and Ryan [18] used AHP for as a decision support system for bid evaluation. Tiwari and Banerjee [19] proposed the use of the AHP process as a decision support system for the selection of a casting process, and Kamal [1] used AHP to select the most suitable contractor in the pre-qualification of process of a project. Chandra and Schall [10] used AHP for economic evaluation of flexible manufacturing system using the Leontif input-output model.

The AHP method cannot straightforwardly be applied to solving uncertain decision problems and imprecisely defined ones. In this case, a natural way to cope with such uncertain judgments is to the comparison ratios as fuzzy judgments as fuzzy sets or fuzzy numbers. The fuzzy set theory was proposed by Zadeh [15], and Bellman and Zadeh [22] described the decision making method in fuzzy environment. Laarhoven and Pedrycz [21] proposed the first studies that applied fuzzy logic principle to AHP. Buckley [9] initiated trapezoidal fuzzy numbers to express the decision maker's evaluation on alternatives with respect to each criterion while Laarthoven and Pedrycz were using triangular fuzzy numbers. Chang [5] introduced a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pair-wise comparison scale of fuzzy AHP.

Deng [6] presented a fuzzy approach for tackling qualitative multi-criteria problems in a simple and straightforward manner. Zhu et al. [13] proved the basic theory of the triangular fuzzy number and improved the formulation the triangular fuzzy number's size. Enea and Piazza [17] focused on the constraints that have to be considered within fuzzy AHP. They used constrained fuzzy AHP in project selection. Kahraman et al. [2] used the fuzzy AHP for comparing catering firms in Turkey. Tang and Beynon [26] used fuzzy AHP for the development and application of a capital investment study. They tried to select the type of fleet car to be adopted by a car rental company. Tolga et al. [16] used fuzzy replacement analysis and AHP in the selection of operating system. Chan and Kumar [3] proposed a model for providing a framework for an organization to select the global supplier by considering risk factors. They used fuzzy extended AHP in the selection of global supplier in the current business scenario. Cheng and Tang [11] studied the selection of appropriate fourth party logistics company in business. They attempted to identify evaluation factors and their weight in the selection process. Fuzzy Analytic Hierarchy Process (FAHP) was utilized to calculate the weight of the various factors. Yang Wu et al. [14] constructed a three hierarchal evolution model to assess disaster prevention in Miaoli County in Taiwan. FAHP was applied for multivariable analyses between interacting and its prevention preparation. Cheng and Tang [11] attempted to identify the critical factors related to bicycle supplier selection. Fuzzy Delphi method and FAHP were used to calculate the weight of the different criteria in order to construct a fuzzy multi-criteria model of bicycle selection. Chiang and Wang [27] assessed management competencies of middle managers, from the point view of supervisors, the candidates for middle managers using FAHP. The result provided ranking of the middle managers on the bases on their management competency. In their work, Jiang et al. [25] coupled the AHP and a fuzzy comprehensive evaluation method to form a new approach. This approach was used to facilitate pair-wise comparison and avoid complex and unreliable process of comparing fuzzy utilities.

Lee [28] studied issued related to the selection of supply chain manager. He suggested that this is a multi-criteria decision making (MCDM) problem since it requires to consider a large number of complex factors. Since many MCDM methods are based on the independence assumptions. He proposed using the Analytic Network Process (ANP) which can deal with all kinds of dependencies, He proposed a method combining multiple intelligence theory with ANP. An empirical study was presented to illustrate the application of his method.

Mainabadi et al. [7] studied the complexity of water resource management issues and its relation to other sciences. The aim of his work was to develop a new process for consensus-based heterogeneous group decision making models. In addition to introducing the decision making process and studying its efficiency in integrated water resources planning and management was presented.

Huang et al. [4] built five models for five insurances, respectively, including life, annuity, health, accident, and investment-oriented insurances. The proposed models consist of AHP, fuzzy logic and Delphi technique. Four variables were selected as the inputs including age, annual income, educational level and risk preference. Using trapezoidal membership function, these input were transformed to fuzzy variables. Twenty experts with many years of experience were interviewed to build these models.

FAHP approach is based on fuzzy concepts with was proposed by Lofti Zadeh. Fuzzy sets and logic are powerful mathematical tools modelling uncertain systems in many scientific, economic, and social fields; and are facilitators for common-sense reasoning in decision making in the absence of complete and precise information. A fuzzy set is an extension of a crisp set; crisp sets only allow full membership or non-membership at all, whereas fuzzy sets allow partial memberships. Zadeh, proposed to use values ranging from 0 to 1 for showing the membership of the objects in a fuzzy set. Here, complete membership is represented as 1 and complete non-membership as 0. Values between 0 and 1 represent intermediate degrees of membership

Fuzzy numbers are a special form of fuzzy sets, a fuzzy number is a fuzzy quantity \tilde{N} that represents a generalization of a real number r, thus is used to approximate r. A fuzzy number \tilde{N} is a convex normalized fuzzy set (Nguyen and Walker [6]. A fuzzy number is characterized by a given interval of real numbers, each grade of membership between 0 and 1.

Triangular fuzzy numbers (TFN) are used in this study; Triangular fuzzy numbers are a special case of fuzzy number [4]. A triangular fuzzy number \tilde{N} is defined by three real numbers, expressed as (l,m,u), where *l* is the lowest possible vale, *m* indicating the most promising value, and *u* indicating the largest possible value that describe the fuzzy event. It is characterized by a linear piecewise continuous membership function $\mu_{\tilde{N}}(x)$ which is described as:

$$\mu_{\tilde{N}}(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-i) & l \le x \le m \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x > u \end{cases}$$
(1)

A triangular fuzzy number \widetilde{N} is represented graphically as shown in Fig. 4.



Fig. 4, A triangular fuzzy number, \tilde{N} .

The basic theory of FAHP is as follows: assume the problem under study has *n* independent alternatives $(\widetilde{A}_1, \widetilde{A}_2,, \widetilde{A}_n)$ with the weights $(\widetilde{w}_1, \widetilde{w}_2,, \widetilde{w}_n)$ respectively. The decision maker does not know in advance the values of \widetilde{w}_i , i =1,2,...,n, but he/she is capable of making pair-wise comparisons between the different alternatives. Also, assume that the quantified judgments provided by the decision maker) on pairs of alternatives $(\widetilde{A}_i, \widetilde{A}_j)$ are represented in an $n \times n$ a fuzzy comparison matrix $\widetilde{A} = \{\widetilde{a}_{ij}\}$ is constructed as:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} \dots \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 \dots \tilde{a}_{2n} \\ \vdots & \vdots \dots \vdots \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} \dots 1 \end{bmatrix}$$
(2)

Where a fuzzy triangular numbers $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ with the following properties:

- 1. $\widetilde{a}_{ij} \approx \widetilde{w}_i / \widetilde{w}_j, i, j = 1, 2, \dots, n$.
- 2. $\tilde{a}_{ii} = 1, i = 1, 2, \dots, n$. All diagonal cells have the value 1.
- 3. $\widetilde{a}_{ji} = 1/\widetilde{a}_{ij} \approx \widetilde{w}_j / \widetilde{w}_i, i, j = 1, 2, \dots, n$.
- 4. $\widetilde{a}_{ij} \cong (\widetilde{w}_i / \widetilde{w}_j) > 1, i, j = 1, 2, ..., n$, If \widetilde{A}_i is more preferred than \widetilde{A}_j .

This implies that matrix \widetilde{A} is a positive and reciprocal matrix with 1's in the main diagonal and hence the decision maker should only provide value judgments in the upper triangle of the matrix. The values assigned to \widetilde{a}_{ij} according to Saaty (AHP) scale are usually in the interval of 1–9 or their reciprocals. Table 3 presents Saaty's scale of preferences in the pair-wise comparison process.

Fable 3 ,	AHP Scale of Preferences in the Pair-
	Wise Comparison Process

Numerical Ratings	Verbal Judgements of Preferences between Alternative <i>i</i> and Alternative <i>j</i> .
1	<i>i</i> is equally preferred to <i>j</i>
3	<i>i</i> is slightly more preferred than <i>j</i>
5	<i>i</i> is strongly more preferred than <i>j</i>
7	<i>i</i> is very strongly more preferred than <i>j</i>
9	i is extremely more preferred than j
2,4,6,8	Intermediate values

The following are the main steps of FAHP:

- 1. State the overall objective of the problem and identify the criteria that influence the overall objective.
- 2. Structure the problem as a hierarchy of goal, criteria, sub-criteria, and alternatives.
- 3. Start by the second level of the hierarchy:
 - Do pair-wise comparison of all elements in the second level and enter the judgments in an *n*×*n* matrix. The values assigned to *a*_{ii}

according to Saaty (AHP) scale are usually in the interval of 1–9 or their reciprocals.

• Calculate the fuzzy priorities by first finding the fuzzy geometric mean geometric for the different rows of the pair-wise comparison of the matrix. Next, the resulting vectors are normalized by dividing each entry by the sum of entries in the vector. The fuzzy geometric mean (*FGM*) is calculated as follows:

$$FGM = \prod_{j=1}^{n} (\tilde{a}_{ij})^{1/n} , i = 1, 2, \dots, n \quad (3)$$

Compute the consistency ratio of the matrix of judgments to make sure that the judgments are consistent.

- 4. Repeat step 3 for all elements in a succeeding level but with respect to each criterion in the preceding level.
- 5. Synthesize the local priorities (fuzzy local weights) over the hierarchy to get a priority (fuzzy composite weight) for each alternative.
- 6. Defuzzifying the resulted fuzzy values of the fuzzy composite weight in order to obtain a crisp value using the Centre of Area method which calculate using the relationship in 5:

$$CN_{ij} = \frac{[(u_{ij} - l_{ij}) + (m_{ij} - l_{ij})]}{3} + l_{ij} \qquad \forall i, j \qquad (4)$$

4 Application of FAHP for Policy Prioritization for Water Conservation in Kuwait

Several factors must be considered in selecting a desalination process, they include the following:

- 1. Product Water Recovery ratio as a function of the feed: The ratio of the amount of the freshwater to the amount of the input seawater. The higher the better.
- 2. Energy Requirement: The amount of energy required to produce freshwater (KW/M^3) , the lower the better.

- 3. Pretreatment Requirements (PRR): The intensity of the pretreatment required by the input sea water prior to desalination. It various from one technology to another, technology with less pretreatment required are more preferable.
- 4. Product water Salinity (PWS): The concentration of salt in the desalinated water, the less the better.
- 5. Turnkey Capital Investment Cost (TCQ): The total cost charged by the contractor constructing the plant. The technology with the least cost is proffered.
- 6. Corrosion potential (CPO): The amount of annual corrosion accumulated in the various equipments due to the operation of the plant.

Table 4 shows the performance of the different desalination technologies in the various factors. This was constructed by consulting several experts with many years of expertise in this field in the region.

Table 4, Linguistic Evaluation of the DifferentDesalination Technologies for the Various Criteria

Parameter	MSF	RO	MED
PRR	Low	Very high	Low
PWS	Low	Medium	Low
WRR	Low	High	Medium high
TCQ	High	Low	Medium
ERQ	High	Low	Medium
CPO	High	Low	Medium high

4.1 Pair-wise comparisons

The hierarchy of the decision problem as shown in Fig. 5 has three levels. The first level is the goal, the second level presents the criteria and the bottom level presents the alternatives. Several water experts in Kuwait were consulted in order to form the different pair-wise comparison matrices.



Fig 5, Analytic hierarchy of desalination plant selection.

In Tables 5, and 6 the different linguistic terms and comparisons were translated into fuzzy

numbers. Table 5 shows the preference between the various criteria, while Table 6 is for comparing the different technologies.

Table 5, Fuzzy Values for the Different LinguisticScales of the Criteria

Linguistic Scales	Scale of Triangular fuzzy number
Absolutely important	(7,9,9)
Very strongly important	(5,7,9)
Essentially important	(3,5,7)
Weakly important	(1,3,5)
Equally important	(1,1,3)

Table 6, Fuzzy Values for the Different Linguistic

 Scales of the Alternatives

Linguistic Scales	Scale of Triangular Fuzzy Number			
	Maximize	Minimize		
Very high	(9,10,10)	(1,1,3)		
High	(7,9,10)	(1,3,5)		
Medium high	(5,7,9)	(3,5,7)		
Medium	(3,5,7)	(5,7,9)		
Medium low	(1,3,5)	(7,9,10)		
Low	1,1,3)	(9,10,10)		

Tables 7-13 present the pair-wise comparisons between the different desalination technologies with respect to each criterion, similarly he geometric mean and the normalized geometric mean is calculate in all cases.

4.2 Synthesizing judgments

The last step in the FAHP is synthesizing of judgments were the composite weight of the different desalination technologies are determined

by combining the fuzzy priorities of the different criteria (factors) as given in Table 9 and that of the different technologies under each criteria as has been calculated in Tables 10-14. Table 15 presents the fuzzy composite weight.

Next the crisp composite weight is calculated through defuzzification process using the centre of area method using the relationship in 4. The composite weight of the different technologies become after normalization becomes follows: MSF (0.232), RO (0.401), and MED (0.367).

5 Results and Conclusion

The results of the analysis shows that the most important criteria to consider when selecting any desalination technology is selecting any water desalination technology is the amount of energy required (ERQ =0.378), followed by the pretreatment requirement (PRR = 0.250), next come the product water recovery ratio (WRR = 0.167), turnkey capital investment cost (TCQ = 0.0996), product water salinity (PWS = 0.066), and corrosion potential (0.043). With respect to water technology type, reverse osmosis came first with 0.401 (40.1%), followed closely by multi-effect distillation (MED) with 0.367 (36.7 %), last is multi-flash desalination with 0.232 (23.2 %). It is apparent that energy requirement should be considered when selecting any technology; in Kuwait energy used in the existing desalination plant is around 5 billion dollars per day. Moreover, pre-treatment and capital are also very important and should be paid attention to in the selection process. Kuwait has to consider building reverse or multi-effect distillation plants in the future.

Criteria	PPR	PWS	WRR	TCQ	ERQ	СРО	Mean of the relative weight	Normalized Mean of the relative weight
PPR PWS WRR TCQ	(1,1,1)(1/7,1/5,1/3)(1,1,3)(1/5,1/3,1)	(3,5,7) (1,1,1) (1,3,5) (1,1,3)	(1,1,3)(1/5,1/3,1)(1,1,1)(1/3,1,1)	(1,3,5) (1/3,1,1) (1,1,3) (1,1,1)	(1,1,1/3) (1/9,1/7,1/5) (1/5,1/3,1) (1/7,1/5,1/3)	(5,7,9) (1,1,3) (3,5,7) (1,3,5)	(224,.236,.258) (.055,.066,.069) (.138,.156,.186) (.09,.091,.112)	(.236,.246,.267) (,057,.069,.072) (.144,.161,.196) (.087,.094,.118)
ERQ CPO	(1,1,3) (1/9,1/7,1/5)	(5,7,9) (1/3,1,1)	(1,3,5) (1/7,1/5,1/3)	(3,5,7) (1/5,1/3,1)	(1,1,1) (1/9,1/9,1/7)	(7,9,9) (1,1,1)	(.323,.373, 392) (035,.040,.040)	(.340,.385,.409) (.036,.042,.042)

 Table 7, Pair-wise Comparison of Criteria with respect to the Goal

Technology	MSF	RO	MED	Mean of the relative weight	Normalized Mean of the relative weight
MSF	(1,1,1)	(3.33,9,10)	(1, 1, 1)	(1.493,2.08,2.15)	(.435.474,. 476)
RO	(.1,.111,.3)	(1,1,1)	(.1,.111,.3)	(.215,.231,.448)	(.048,.052, .130)
MED	(1,1,1)	(3.33,9,10)	(1,1,1)	(1.494, 2.08, 2.15)	(.435,.474,.476)

Table 8, Pair-wise Comparison of the different technologies with respect to PRR

Table 9, Pair-wise Comparison of the different technologies with respect to PWS

Technology	MSF	RO	MED	Mean of the relative weight	Normalized Mean of the relative weight
MSF	(1,1,1)	(1, 1.666,3)	(1,1,1)	(1,1.285,1.44)	(.333, .385, .429)
RO	(.333,.6,1)	(1,1,1)	(.333,.6,1)	(.481,.712, 1)	(.143,.230,.333)
MED	(1,1,1)	(1, 1.666,3)	(1,1,1)	(1,1.285,1.44)	(.333,.385,.429)

Table 10, Pair-wise Comparison of the different technologies with respect to WRR

Technology	MSF	RO	MED	Mean of the relative weight	Normalized Mean of the relative weight
MSF	(1,1,1)	(.111,.3,.143)	(.143,.2,.333)	(.251,.306,.464)	(.059,.077,.136)
RO	(3.333,7,9)	(1,1,1)	(1.111, 1.28, 1.4)	(1.55,2.14, 2.26)	(.455,.529,.538)
MED	(3,5,73)	(.714,.778,.9)	(1,1,1)	(1.39,1.53, 1.76)	(.385,.409,.412)

Table 11, Pair-wise Comparison of the different technologies with respect to TCQ

Technology	MSF	RO	MED	Mean of the relative weight	Normalized Mean of the relative weight
MSF	(1,1,1)	(.111,.3,.5)	(.33,.43,.56)	(.333,.505,.652)	(.077,.15,.208)
RO	(2, 3.33, 9)	(1,1,1)	(1.11, 1.43, 3)	(1.305, 1.682,3)	(.417,.5,.692)
MED	(1.8,2.33, 3)	(.333,.7,.9)	(1,1,1)	(1, 1.744, 1.778)	(.231, .35, .375)

Table 12, Pair-wise Comparison of the different technologies with respect to ERQ

Technology	logy MSF RO		MED	Mean of the relative weight	Normalized Mean of the relative weight	
MSF	(1,1,1)	(.111,.3,.5)	(.2,.429, .9)	(.281,.505,.766)	(.067,.15,.243)	
RO	(2, 3.333, 9)	(1,1,1)	(1.43, 1.8, 1.8)	(1.533, 1.68, 2.53)	(.5,.486,.6)	
MED	(1.11,2.33,5)	(.55,.55,.7)	(1,1,1)	(.851,1.177,1.406)	(.270,.333, .35)	

Table 13,	Pair-wise	Comparison	of the	different	technologies	with respect to CPO
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Technology	echnology MSF		MED	Mean of the relative weight	Normalized Mean of the relative weight	
MSF	(1,1,1)	(.111,.3,.5)	(.333,.6,.714)	(.333,.564,.709)	(.077,.167,.227)	
RO	(2, 3.33, 9)	(1,1,1)	(,1.428,2,3)	(1.419,1.88,3)	(.454, .556, .692)	
MED	(3,1.667,1.4)	(.333,.5,.7)	(1,1,1)	(.941,.993,1)	(.231 .278,.318)	

 Table 14, Pair-wise Comparison of Criteria with respect to the Goal

Criteria	PPR (.236,.246,.267)	PWS (.072,057,.069)	WRR (.144,.161,.196)	TCQ (.087,.094,.118)	ERQ (.409,.385,.340)	CPO (.042,0.036,.042)	Fuzzy Composite weight
MSF	(.435.474,. 476)	(.333,.385,.429)	(.059,.077,.136)	(.077,.15,.208)	(.067,.15,.243)	(.077,.167,.227)	(.167,.226,.283)
RO	(.048,.052, .130)	(.143,.230,.333)	(.455,.529,.538)	(.417,.5,.692)	(.5,.486,.6)	(.454,.556,.692)	(.339,.373,.462)
MED	(.435,.474,.476)	(.333,.385,.429)	(.385,.409,.412)	(.231, .35,.375)	(.270,.333, .35)	(.231.278,318)	(.312,.374,.385)

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